Experimental Considerations for Ground-based Testing of Lunar Construction Technologies.

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Introduction: The Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) project, under NASA's Game Changing Division (GCD) aims to research, develop, and demonstrate lunar surface construction capabilities [1]. A fundamental step in lunar infrastructure development is to quantify the geotechnical properties of lunar regolith, such as shear strength (Mohr-Coulomb cohesion and angle of internal friction), compression and bearing properties, and angle of repose. Knowledge of these geotechnical properties enables the prediction of forces and displacements associated with lunar infrastructure development processes including excavation and constructing landing pads, habitats, shelters, and roadways. Through ground-based testing of autonomous lunar systems performed using relevant hardware (e.g., robotic arms) in appropriate lunar regolith simulants, the developed hardware/technology and tool paths can be validated. Such testing also generates data to give insight into the geotechnical regolith properties on the lunar surface.

Design of Experiments (DoE): Data from in-lab testing of lunar hardware ground interactions can serve as a reference to inform on the geotechnical properties of lunar regolith. Geotechnical studies are concerned with normal and shear loads, so experiments that involve compressive and shear forces, and combinations thereof, should be emphasized. These include pressure-sinkage (push down with a known amount of force and measure displacement), shearing (pushing down with a known force followed by horizontal translation), excavation, and induced slope failure.

A resource-efficient DoE created using Taguchi methods [2] minimizes the number of experiments needed to explore the parameter space of the input factors. The goal of Taguchi methods is to design robust experiments that are informative in uncontrolled conditions [2]. A factorial DoE tests every combination of input factors [3], but available resources do not always allow for the extensive experimentation required by a factorial DoE. To maximize the knowledge gained from laboratory testing of lunar construction hardware and to better constrain geotechnical properties, combinations of Taguchi and factorial DoE are being investigated for MMPACT and other lunar missions.

Geotechnical Data Analysis: Pressure-sinkage experiments provide information on the bearing strength and stiffness of regolith [4] and are directly relevant to lunar construction efforts. Key geotechnical parameters are the Mohr-Coulomb parameters of cohesion and angle of internal friction, which can be estimated by slope failure analyses [5] and shearing experiments [6] which also allow estimation of sliding strength (adhesion and angle of external friction) [7]. Excavation forces are typically a convolution of 2D horizontal and vertical forces [8] and depend on depth, gravity, and the frictional and adhesive properties of the regolith being manipulated [8]. Geotechnical data analysis and force prediction techniques range from analytical models that generally assume simple planar geometries [8] to geometrically-flexible numerical methods such as finite element models (FEMs) [9] and discrete element models (DEMs) [10].

Conclusions: Quantifying the geotechnical properties of lunar regolith is key to lunar infrastructure development efforts, as improper ground-based testing and construction site characterization puts personnel, hardware, and developed infrastructure at risk. Proper testing of regolith-tool interactions in a controlled laboratory setting generates data for comparison to lunar surface data enabling predicition and modeling of forces observed during lunar infrastructure development.

References:

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